CROP YIELD-WATER USE RELATIONS FOR WYOMING

Larry Pochop
K. James Fornstrom
Eugene Kottwitz

November 1987 WWRC-87-05

Agricultural Engineering Department
University of Wyoming

Research Project Technical Completion Report
(USGS G-1262, Project No. 05)

Prepared for:
Department of the Interior
U.S. Geological Survey

The activities on which this report is based were financed in part by the Department of the Interior, U.S. Geological Survey, through the Wyoming Water Research Center.

Wyoming Water Research Center
University of Wyoming
Laramie, Wyoming

ABSTRACT

A study was conducted to test existing production models for predicting yield response to water. The study utilized winter wheat yield data from Archer, Gillette, and Sheridan, Wyoming for the period 1950 through 1983. The FAO evapotranspiration and yield-water use models were utilized to estimate yields which were compared with actual yields at the three sites. Average estimated yields ranged from 5 percent lower to 13 percent and 22 percent higher than actual yields at Archer, Gillette, and Sheridan, respectively. Statistical analyses indicated that there were no significant differences between the actual and estimated yields at any of the three locations. Additional studies are being conducted to better define the soil water versus yield relationships.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

Assessment of the economic effects of proposed water projects as well as the on-farm management of Wyoming's water resources is dependent, in part, upon the ability to define the relative consequences on crop yields of various management alternatives. Irrigation scheduling, deficit irrigation, and improvement of water use efficiencies are examples of management practices which affect production costs and water consumption.

Most measurements of crop response to water use, have been for conditions where soil moisture was not limited. That is, crop response to maximum water use has been measured extensively, whereas few measurements are available for crop response under conditions of limited soil moisture. In addition, most measurements of water use rates have been under conditions of unlimited soil moisture. Methods for predicting water use rates have not been calibrated extensively for limited soil moisture conditions. A number of critical water use questions involve limited soil moisture conditions. Among these are conveyence losses, return flows, and deficit irrigation.

The applicability of various crop response models to specific locations remains largely undefined. The transferability of crop response models between sites has met with varied success, even within the same study region. A major difficulty in assessing model applicability has been the general lack of suitable data, especially long-term yield data. This project investigated the applicability of crop response models through use of existing University of Wyoming Plant Science winter wheat yield data from 1951 through 1984.

Objectives

The overall objective of this study was to investigate the applicability of crop yield-water use models to crops grown in high altitude locations. Specific objectives were:

1. To gather historical crop yield and climatic data for use in crop yield-water use models for the State of Wyoming.

2. To test existing production models for applicability in predicting yield response to water and the need for definition of growth stages and soil and climatic parameters.

3. To outline the feasibility and/or need of additional studies to define the yield-water use relationships of various crops.

The study was developed to use existing yield and climatic data with no field studies required. The only field data which were required was information on soil moisture holding capacities at the sites for which yield data were available. Winter wheat yield trials have been conducted annually at several locations in eastern Wyoming. The work has been conducted by the University of Wyoming, with the Wyoming Wheat Commission acting as an advisory group and providing financial support. The results of these winter wheat trials were used as the main source of yield data for this study.

Related Studies

Considerable research has been conducted to define the response of various crops to soil moisture conditions. As early as 1892, Buffum gave suggestions concerning irrigation before heading to improve the ability for winter wheat in Wyoming to reach maturity. More recently, however, attention has been given to developing crop yield models. In order to quantify the effect of water stress, many of these models have attempted to define the relationship between yield and crop water use with decreased yields resulting from less than maximum water use. Most studies indicate that yield is generally linearly related to evapotranspiration, but the relationship may differ significantly between sites due to factors such as different planting dates or growing seasons. Thus, local calibrations may be required.

In Wyoming, winter wheat yield trials have been conducted annually at several locations (e.g., Kolp, 1981). These studies provide a source of yield data which may be used to test the crop response models. Since the models require measurements and/or estimates of actual and maximum crop water use, the ability to estimate evapotranspiration is imperative for tests of the applicability of the crop response models. Considerable research has been conducted in recent years to improve evapotranspiration estimates in Wyoming (e.g., Pochop and Burman, 1987). Previous research concerning crop yields in Wyoming includes an analysis of the effects of precipitation on county-wide yields (Pochop, et al., 1973). Yield data in that instance were county-wide averages and, thus, were not as site specific as are the yields from the variety trials discussed above.

Chapter 2

METHODS

Most current crop yield-water use models are based on the evapotranspiration ratio, i.e. the ratio of the actual evapotranspiration to the maximum evapotranspiration. One of the most recently developed models and one which is claimed to have wide applicability is the crop yield-water use model by Doorenbos and Kassam (1979) generally referred to as the FAO yield-water use model.

The FAO yield-water use model was selected for testing herein, partly because of recent experience with FAO evapotranspiration models in Wyoming and partly because the model requires data that were either available or could be acquired relatively easily. Maximum and actual evapotranspiration were estimated using the FAO modified version of the Blaney-Criddle model. The model gives actual evapotranspiration as a percentage of the maximum evapotranspiration based on the level of available soil water and the depletion level.

Data required as input into the yield-water use and evapotranspiration models included crop yields, climatological data, and soil water holding capacities. The yield and climatological data were obtained from historical records at the Archer, Gillette, and Sheridan Research Centers while soil water holding capacities were determined from field sampling and laboratory analyses for each site.

Crop Yield-Water Use Model

The FAO yield-water use model relates relative yield decrease to relative evapotranspiration deficit through use of an empirically derived yield response factor. The equation is given as

$$(1 - Ya / Ym) = ky (1 - ETa / ETm)$$

where:

- Ya = actual yield
- Ym = maximum yield
- ETa = actual evapotranspiration for a period
- ETm = maximum evapotranspiration for a period
- ky = yield response factor for the period.

Values for ky are given by Doorenbos and Kassam (1979) for specific growth periods and for the entire growing season for a number of different crops. Individual growth periods for which ky values are given include the vegetative, flowering, yield formation, and ripening periods. The values of ky for individual growth periods were developed by inducing stress on the crop in only that one period. Thus, the combined effect of water stress in more than one period is largely undefined. The only combination of periods for which a value of ky is given for winter wheat is for stress in the vegetative and flowering periods. Thus, for stress in other combinations of periods, the seasonal ky value must be used with the seasonal evapotranspiration ratio (ETa /ETm).

The FAO yield-water use model is based on the assumption that soil water is the only factor limiting yield for a particular climatic location. As stated by Doorenbos and Kassam (1979), "the relationships presented refer to high producing varieties, well-adapted to the growing environment, growing in large fields where optimum agronomic and irrigation practices, including adequate input supply, except for water, are provided." Since the Cheyenne variety of winter wheat has been among the higher producing varieties over the years it would appear that this variety is well adapted to the growing environment of eastern Wyoming. The large field assumption was probably not entirely met, since the variety trial plot sizes were four rows wide with row spacings of 0.254 or 0.305 meters and 5.03 meters long. However, the plots were grown within large fields. The tillage and fertilization practices were not completely recorded and, thus, could not be defined exactly. However good tillage practices were usually followed on the variety trial plots. Years in which other yield reducing factors such as pests and diseases were present could not always be defined either.

Evapotranspiration

The FAO evapotranspiration model (Doorenbos and Pruitt, 1977) estimates maximum and actual evapotranspiration for a particular crop by first estimating a reference evapotranspiration. Reference evapotranspiration is defined as "the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water". Crop coefficients are used to convert reference evapotranspiration, ETr, to maximum evapotranspiration, ETm. The equation for reference evapotranspiration is

$$ETr = c\ [P\ (0.46T + 8)]$$

where:

ETr = reference crop evapotranspiration in mm/day
T = mean daily temperature in degrees Celsius
P = the daily percentage of total annual daytime hours
c = an adjustment factor which depends on minimum relative humidity, percent sunshine, and daytime wind estimates.

Values for c were originally obtained from a set of figures given by Doorenbos and Pruitt (1977). Frevert et al. (1983) recognized the need for a regression equation as a substitute for the figures if computer analysis was to be used. In either case, exact values of the climatic parameters used to define the c value are not required. The modified equation for ETr is

$$ETr = A + B\ [P\ (0.46T + 8]$$

where:

$A = 0.043X1 - X2 - 1.41$

$B = A0 + A1X1 + A2X2 + A3X3 + A4X4$

X1 = minimum relative humidity as a percent

X2 = percent sunshine expressed as the ratio of sunshine hours to day length

X3 = daytime wind speed in meters per second

X4 = X1X2

X5 = X1X3

A0 = 0.81917

A1 = -0.0040922

A2 = 1.0705

A3 = 0.065649

A4 = -0.0059684

A5 = -0.0005967

Crop coefficients used to convert ETr to ETm are given by Doorenbos and Kassam (1979). Coefficients are given for initial, crop development, mid-season, late season, and harvest crop development stages as well as for the entire growing period. The stage lengths and crop coefficient values assumed for this study are given in Table 1.

Actual evapotranspiration is related to maximum evapotranspiration by

$$ETa = ETm\,(St\ D)/((1 - p)Sa\ D)$$

where:

p = allowable soil water depletion fraction

D = rooting depth in meters

Sa = maximum available soil water in millimeters per meter

St = available soil water at time t in millimeters per meter

The allowable soil water depletion fraction is dependent upon the value of ETm. Values for p for winter wheat as given by Doorenbos and Kassam (1979) are given in Table 2. Maximum rooting depth of winter wheat was assumed to be 1.0 meter. Given the maximum rooting depth, the current rooting depth was calculated using the model given by Borg and Grimes (1985) as

TABLE 1. ASSUMED CROP DEVELOPMENT STAGE LENGTHS AND COEFFICIENTS

CROP DEVELOPMENT STAGE	STAGE LENGTH (DAYS)	CROP COEFFICIENT
INITIAL	21	0.35
CROP DEVELOPMENT	31	0.75
MID-SEASON	67	1.12
LATE SEASON	41	0.70
TOTAL SEASON	160	

TABLE 2. ALLOWABLE SOIL WATER DEPLETION FRACTION FOR WHEAT*

MAXIMUM ET (mm/day)	2	3	4	5	6	7	8	9	10
SOIL WATER DEPLETION FRACTION	0.80	0.70	0.60	0.50	0.45	0.425	0.375	0.35	0.30

* From Doorenbos and Kassam (1979)

$$RRD = 0.5 + 0.5 \sin(3.03TR - 1.47)$$

where:
- RRD = relative rooting depth given as the ratio of current rooting depth divided by the maximum rooting depth
- TR = relative time given as the current day after planting divided by the total days to maturity

Soil samples were taken in July of 1986 to determine soil water holding capacities and maximum available soil water values. Samples were taken at depths of 0.15, 0.46, and 0.76 meters in summer fallow areas near many of the variety trial plots. Six, three, and five samples were taken at Archer, Gillette, and Sheridan, respectively (Tables A1-A3). The samples at each site were averaged with results summarized in Table 3. At Archer, a hard sandy layer was encountered at a depth of 0.60 to 0.70 meters which made sampling very difficult and which probably restricted root growth. The five sets of samples taken at Sheridan could be described as being two sets from a draw and three sets from an upland field with the samples from these two locations being quite different. The Gillette substation was abandoned after 1978.

Available soil water St at time t is determined by assuming that the current value of available soil water is known. Then the actual evapotranspiration can be determined. The new value of St is the current value plus any contributions to soil water from precipitation minus actual evapotranspiration between the current time and the time that the new value is desired. The initial current value of available soil water is usually determined at the beginning of the spring growing season for winter wheat.

Two approaches could be used to define the initial St value. The first, which was used for this study, is to assume that the soil profile is full at the beginning of the spring growing season. In this approach, the soil profile depth considered was 1.0 meter at Gillette and Sheridan and 0.67 meter at Archer. The second approach is to predict the initial soil moisture based on available soil moisture and climatic data. This approach would be more realistic, but data required to develop the prediction equations are very limited. As a first approximation, the assumption of soil moisture at field capacity at the beginning of the spring growing season was considered adequate.

Yield Data

Crop yield data were obtained from University of Wyoming Plant Science variety trials (e.g. Pfeifer and Kolp, 1958; Dalrymple and Kolp, 1984; Kolp, 1967 and Kolp 1986). These studies have been conducted from 1951 to the present. The studies were located at various cooperative farms in eastern Wyoming as well as state operated stations at Archer, Gillette, and Sheridan. Yield data from the three state Research and Extension Centers were used herein, although the variety trials at Gillette were discontinued after 1979. All data used was for the Cheyenne variety since this variety was used as a benchmark in the trials and had more years of data than any other variety. All trials were on summer fallow ground.

TABLE 3. SOIL WATER HOLDING PARAMETERS AT THE THREE SITES

LOCATION	DEPTH (m)	BULK DENSITY (g/cm3)	FIELD CAPACITY MOISTURE CONTENT (%)	PERMANENT WILTING POINT MOISTURE CONTENT (%)	AVAILABLE WATER HOLDING CAPCITY (mm/m)
ARCHER	0.15	1.55	19.7	9.1	160
	0.46	1.58	23.9	13.5	164
	0.76	1.60	17.6	8.1	150
GILLETTE	0.15	1.74	10.6	3.8	117
	0.46	1.63	21.1	13.0	132
	0.76	1.61	17.0	9.9	112
SHERIDAN	0.15	1.59	23.0	12.6	162
	0.46	1.57	24.1	14.2	153
	0.76	1.61	21.7	12.3	152

Annual reports for the variety trials were not available for all combinations of year and location. Thus, yield data were not available for all years (Table 4). In addition, factors such as disease, insects, hail, and frost which cause yield reductions were not always reported. This caused some difficulty with the yield-water use model which assumes that soil water is the only limiting factor on yields.

The possibility of a time trend in the yield data was investigated. Linear regressions of yield versus year indicated that for Archer and Sheridan the time effect was negligible. For Gillette, however, yield did appear to increase slightly over the years.

Climatological and Soil Moisture Data

The climatological data was from the National Weather Service Cooperative Network as supplied by the Wyoming Water Research Center (1983). Long term climatic data at Archer, Gillette, and Sheridan were limited to daily maximum and minimum temperature and precipitation. Wind, humidity, and radiation data required for the evapotranspiration models were taken from a climatic atlas (USDC, 1968).

Soil moisture measurements were available from Archer for the years 1963 through 1968. Measurements from stubble mulch plots were used herein to represent field conditions for the fallow period between winter wheat crops. Soil moisture was measured with a neutron probe at depths of 0.15, 0.30, 0.61, 0.91, 1.22, and 1.52 meters. The total soil water to 0.91 meters was taken as the sum of the first three depth increments.

TABLE 4. YIELD DATA FOR CHEYENNE WINTER WHEAT IN EASTERN WYOMING

YEAR	YIELD (M^3/HA) ARCHER	GILLETTE	SHERIDAN
1950	--	--	3.81
1951	2.86	1.25	2.84
1952	1.65	0.61	2.93
1953	--	1.66	1.60
1954	--	--	1.40
1955	--	1.40	2.35
1956	1.60	--	--
1957	2.57	2.31	2.80
1958	3.63	1.68H	--
1959	1.10	1.46	--
1960	2.00	2.13	2.51
1961	-- S	1.99	2.42
1962	3.43H	3.54R	3.04
1963	1.98	3.44	2.73T
1964	1.59	3.05	4.68
1965	-- S	-- SR	3.69HR
1966	1.57	1.99	2.87
1967	3.87T	4.68	4.55
1968	3.34H	3.24	4.80
1969	1.98H	-- H	3.67T
1970	--	2.69	1.62
1971	2.54	2.93	4.62
1972	3.16HP	3.99	4.48H
1973	1.39	2.12	2.07
1974	3.06	-- H	2.82
1975	1.93	3.34	1.52
1976	1.03	-- H	2.64
1977	-- H	2.63	2.82H
1978	1.42S	3.18	2.19
1979	1.55	-- S	3.75
1980	0.90	--	4.39
1981	2.76	--	5.42
1982	3.88	--	4.61
1983	3.55	--	3.64

-- No yield data available
H Hail damage
P Missing precipitation data
R Rust
S Poor fall stand
T Missing temperature data

Chapter 3

RESULTS AND DISCUSSION

Results using two approaches for predicting winter wheat yields are shown herein. The first approach attempts to predict yields from a linear regression of yields versus summer season ETa for each of the three locations. The second approach is the application of the FAO yield-water use model to calculate yields. Comparisons of actual versus estimated yields are made for each location. All analyses have been performed assuming the soil moisture at the beginning of the growing season at field capacity. Since soil moisture is a critical factor in yield estimates, a method of estimating initial soil moisture is presented.

Yields vs Actual Evapotranspiration

An approach to yield estimates sometimes used is that of predicting yields directly from actual evapotranspiration (e.g., Hill, et al., 1982 and Hill, et al., 1983). Actual and maximum evapotranspiration for four crop development periods and the entire season were calculated herein using the methods presented in the previous chapter (Tables A4-A6). The seasonal results are summarized in Table 5.

Actual yields (Table 6) were regressed against actual evapotranspiration estimates for each of the three locations Archer, Gillette, and Sheridan. Results at Archer and Gillette were similar with coefficients of determination of 0.35 and 0.45, respectively, while the results at Sheridan were very poor with a cofficient of determination of 0.0002 (Table 7).

The yield versus evapotranspiration results were not unexpected. In general, however, results here were poorer than those obtained by Hill et al. in the studies cited above for spring wheat and other crops. The exceptionally poor results for Sheridan might be partly explained by the yield data being taken from two sites at Sheridan, an upland site and a draw. The yield data from these two sites were not able to be identified by year.

Actual vs Estimated Yields

All analyses were completed with a value of 1.00 for the yield response factor ky in the FAO yield-water use model. The value of 1.00 is given by Doorenbos and Kassam (1979) for the entire growing season for winter wheat. Yields were estimated using the FAO yield-water use model for each year for which actual winter wheat yield data were available at Archer, Gillette, and Sheridan. The analyses were completed assuming that the initial soil moisture at the beginning of the spring growing season was at field capacity. Analyses were performed separately for the three stations rather than combining the data.

Maximum yields, Ym, were taken from the yield data of table 4 with slight modifications based on the recommedations of Doorenbos and Kassam (1979). The highest recorded yields were 3.87, 4.68, and 5.42 cubic meters per hectare at Archer, Gillette, and Sheridan, respectively. The suggested range for maximum yield of winter wheat from Doorenbos and Kassam (1979) is 5.2 to 7.8 cubic meters per hectare. Maximum yield values of 4.30, 5.20, and 6.00 cubic meters per hectare were assumed for Archer, Gillette, and Sheridan, respectively. Thus the highest recorded yield values were, approximately 90% of the assumed maximum yield values.

Results of the analyses indicate that the average of estimated yields was 5 percent lower than the average of actual yields at Archer while the averages of estimated yields were 22 and 13 percent higher than the averages of actual yields at Gillette and Sheridan, respectively (Table 6). The higher values of estimated yields versus actual yields at Gillette and Sheridan may be explained, in part, by the assumption of the soil moisture being at field capacity at the beginning of the spring growing season. Such an assumption would tend to give higher than expected estimated yields from the FAO model. Although the results for Archer are not consistent with this trend, it appears that the FAO yield-water use model would have performed slightly better if more accurate estimates of soil water at the beginning of the spring growing season were possible.

Statistical analyses of the results using a t-test and a 5% confidence level indicates that there were no significant differences between the actual versus estimated yields at any of the three locations (Table 8). The results in Table 8 show that the lowest t value was calculated for Archer. Calculated t values at Gillette and Sheridan were much closer to the critical values for a 5% confidence level.

Although the t test assumed both equal means and standard deviations for the actual and estimated yields, comparisons (Table 8 and Figure 1) show that the variation of the actual yields were greater than those for the estimated yields at all three locations. This implies that, although no statistical differences occurred between the actual and estimated yields, the FAO model produced yield estimates that were not as variable as the actual yields. This was expected, since the FAO model assumed that soil moisture was the only limiting factor and did not give yield estimates responding to other factors such as diseases, hail, and frost which would have affected actual yields. Histograms of actual versus estimated yields, as given in Fig. 1, further show the greater variability of actual yields.

TABLE 5. ACTUAL AND MAXIMUM EVAPOTRANSPIRATION ESTIMATES

	ARCHER		GILLETTE		SHERIDAN	
YEAR	ETa	ETm	ETa	ETm	ETa	ETm
1950	-	-	-	-	231	391
1951	221	391	175	396	237	410
1952	209	437	208	458	259	463
1953	-	-	278	406	257	417
1954	-	-	-	-	196	432
1955	-	-	246	431	295	425
1956	251	444	-	-	-	-
1957	262	397	248	416	300	434
1958	192	441	-	-	-	-
1959	188	425	207	425	-	-
1960	175	461	200	447	202	465
1961	-	-	169	443	232	459
1962	232	447	284	343	268	457
1963	174	465	312	453	-	-
1964	164	414	318	419	333	437
1965	-	-	-	-	215	425
1966	154	450	205	442	215	449
1967	-	-	312	405	283	404
1968	271	404	248	385	282	391
1969	190	448	-	-	-	-
1970	-	-	260	412	301	431
1971	217	417	236	436	270	431
1972	-	-	244	436	252	428
1973	154	410	218	419	256	405
1974	172	461	-	-	208	421
1975	199	404	287	387	314	383
1976	168	450	-	-	250	460
1977	-	-	210	476	284	457
1978	188	448	310	436	339	452
1979	202	436	-	-	233	420
1980	194	437	-	-	246	468
1981	281	460	-	-	264	455
1982	245	386	-	-	250	392
1983	296	365	-	-	212	406
AVGS	208	429	246	422	258	430

* Evapotranspiration is in units of mm.

TABLE 6. ACTUAL YIELDS VS YIELDS ESTIMATED USING FAO MODEL

	ARCHER		GILLETTE		SHERIDAN	
YEAR	ACTUAL	ESTIMATED	ACTUAL	ESTIMATED	ACTUAL	ESTIMATED
1950	--	--	--	--	3.81	3.53
1951	2.86	2.43	1.25	2.30	2.84	3.47
1952	1.65	2.06	0.61	2.36	2.93	3.36
1953	--	--	1.66	3.56	1.60	3.70
1954	--	--	--	--	1.40	2.72
1955	--	--	1.40	2.97	2.35	4.16
1956	1.60	2.43	--	--	--	--
1957	2.57	2.83	2.31	3.10	2.80	4.15
1958	3.63	1.87	--	--	--	--
1959	1.10	1.90	1.46	2.54	--	--
1960	2.00	1.63	2.13	2.32	2.51	2.60
1961	--	--	1.99	1.98	2.42	3.03
1962	3.43	2.23	3.54	4.31	3.04	3.51
1963	1.98	1.61	3.44	3.58	--	--
1964	1.59	1.70	3.05	3.95	4.68	4.57
1965	--	--	--	--	3.69	3.03
1966	1.57	1.47	1.99	2.42	2.87	2.87
1967	--	--	4.68	4.00	4.55	4.21
1968	3.34	2.88	3.24	3.35	4.80	4.32
1969	1.98	1.83	--	--	--	--
1970	--	--	2.69	3.28	1.62	4.19
1971	2.54	2.23	2.93	2.82	4.62	3.76
1972	--	--	3.99	2.92	4.48	3.54
1973	1.39	1.61	2.12	2.70	2.07	3.93
1974	3.06	1.60	--	--	2.82	2.96
1975	1.93	2.12	3.34	3.86	1.52	4.91
1976	1.03	1.60	--	--	2.64	3.27
1977	--	--	2.63	2.29	2.82	3.73
1978	1.42	1.81	3.18	3.70	2.19	4.49
1979	1.55	2.00	--	--	3.75	3.32
1980	0.90	1.91	--	--	4.39	3.16
1981	2.76	2.63	--	--	5.42	3.49
1982	3.88	2.73	--	--	4.61	3.83
1983	3.55	3.49	--	--	3.64	3.13
AVGS	2.22	2.11	2.55	3.06	3.20	3.62

* All yields are in cubic meters per hectare.
The seasonal value of ky used was 1.00

TABLE 7. RESULTS OF YIELDS VS ACTUAL EVAPOTRANSPIRATION

LOCATION	YIELD EQUATION	COEFFICIENT OF DETERMINATION
ARCHER	Ya = -0.5138 + 0.0131 ETa	0.35
GILLETTE	Ya = -1.0388 + 0.0146 ETa	0.45
SHERIDAN	Ya = 3.1054 + 0.00038ETa	0.0002

* Actual evapotranspiration was calculated using the FAO procedures. Yields are in cubic meters per hectare while evapotranspiration is in mm.

TABLE 8. RESULTS OF T TEST FOR ACTUAL VS ESTIMATED YIELDS*

	ACTUAL YIELDS		ESTIMATED YIELDS			
LOCATION	MEAN	ST DEV	MEAN	ST DEV	CALCULATED T VALUE	CRITICAL T VALUE**
ARCHER	2.22	0.90	2.11	0.51	0.52	2.01
GILLETTE	2.55	1.00	3.06	0.68	1.99	2.02
SHERIDAN	3.20	1.13	3.62	0.58	1.72	2.00

* Estimated yields were caculated using the FAO yield-water use model. Yields and standard deviations are in cubic meters per hectare.
** The critical t value is for a 5% confidence level.

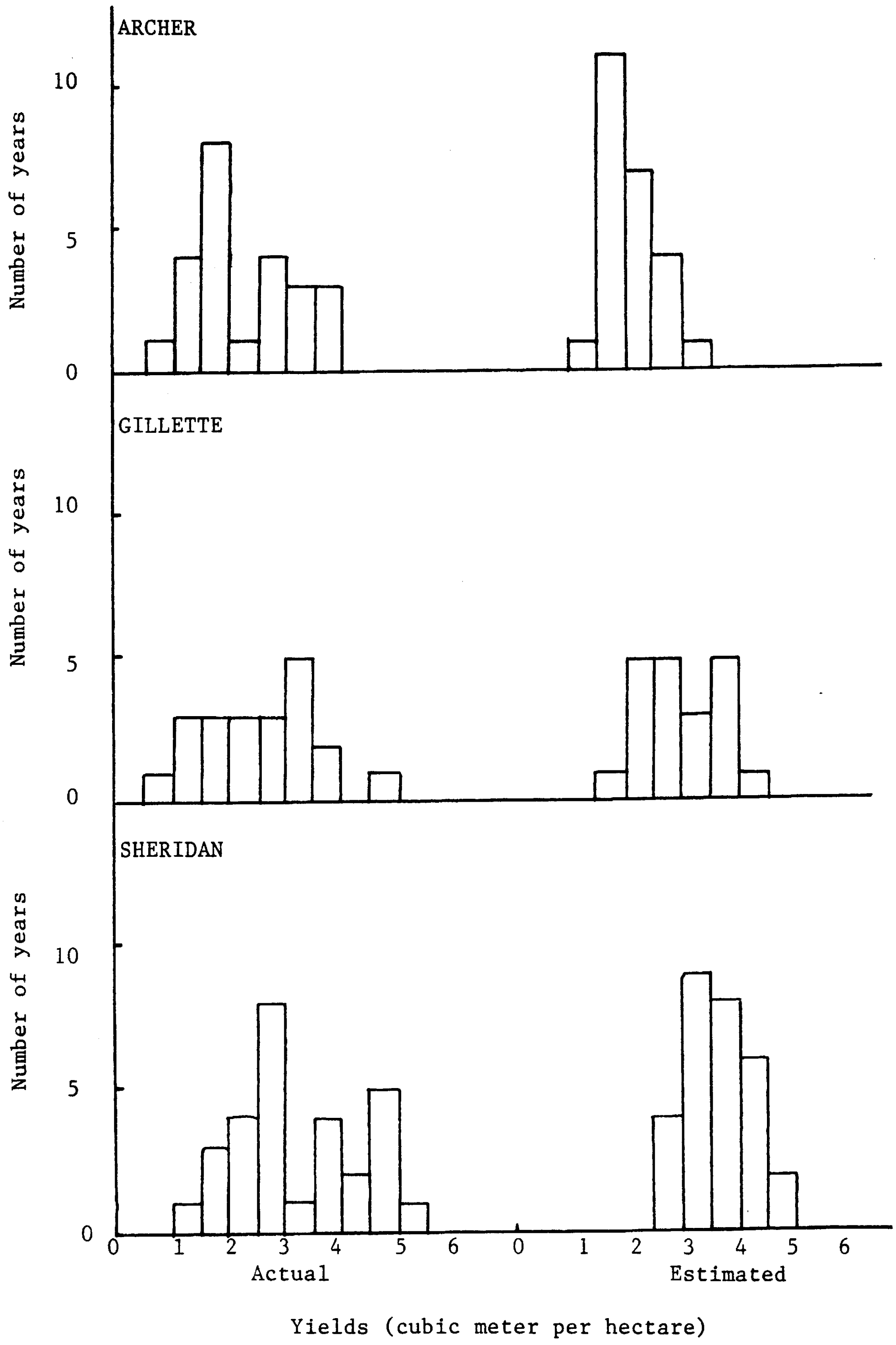

Figure 1. Histograms of actual and estimated yields.

Chapter 4

SUMMARY

The primary purpose of this study was to test existing production models for predicting yield response to water. The study utilized existing yield data obtained from winter wheat yield trials at Archer, Gillette, and Sheridan, Wyoming. Climatic data and soil moisture holding capacities at the three sites were also used.

Two production models were tested. Yields at each of the three sites were regressed against actual evapotranspiration which was estimated using the FAO procedures. Low coefficients of determination were obtained for these regressions. The second approach was to use the FAO yield-water use model to predict estimated yields which were then compared with actual yields. Average estimated yields were 5 percent lower, 13 percent higher, and 22 percent higher than actual yields at Archer, Sheridan, and Gillette, respectively. Statistical analyses using a t-test and a 5% confidence level indicated that there were no significant differences between the actual and estimated yields at any of the three locations. However, the variations of the actual yields were greater than the variations of the estimated yields at all three locations.

All analyses were performed assuming that the soil moisture at the beginning of the spring growing season was at field capacity. Improvements in the estimates might be possible with better estimates of the soil moisture at the beginning of the spring growing season. Work on this aspect will continue through a project funded by the High Plains Regional Climate Center located at Lincoln, Nebraska. Soil moisture measurements were taken during the summer of 1987 in winter wheat fallow and stubble at two sites in eastern Wyoming. Since soil moisture was found to be a critical factor in yield-water use models, field data will be taken to better define specific relationships. In addition, field measurements of soil moisture will be used to calibrate models for estimating actual evapotranspiration which is an important parameter in most yield-water use models.

LITERATURE CITED

Borg, H. and D. W. Grimes, 1986. Depth development of roots with time: an empirical discription. Trans. Am. Soc. Agric. Engr., 29(1):194-197.

Dalrymple, A.W. and B.J. Kolp. 1984. Winter wheat varieties for Wyoming: 1984. University of Wyoming Agricultural Experiment Station RJ 194.

Doorenbos, J. and A. H. Kassam, 1979. Yield response to water. FAO Irrigation and Drainage Paper 33, Rome.

Doorenbos, J. and W. O. Pruitt, 1977. Crop water requirements. FAO Irrigation and Drainage Paper 24, Rome.

Frevert, D. K., R. W. Hill, and B. C. Braaten, 1983. Estimation of FAO Evapotranspiration Coefficients. J. Irrig. and Drainage, ASCE, 109(2):265-270.

Hill, R. W., R. J. Hanks, and J. L. Wright, 1982. Crop yield models adapted to irrigation scheduling programs. Final Report, USDA-ARS Cooperative Research No. 58-9AHZ-9-440 and Utah Agricultural Experiment Station Project No. 796.

Hill, R. W., E. L. Johns, and D. K. Frevert, 1983. Comparison of equations used for estimating agricultural crop evapotranspiration with field research. Bureau of Reclamation, Engineering and Research Center, Denver, CO. 80225.

Kolp, B.J. 1967. Winter grain varieties for Wyoming. University of Wyoming Agricultural Experiment Station B 466.

Kolp, B. J., 1981. Dryland winter wheat varieties for Wyoming. Univ. Wy. Agric. Exp. Sta. RJ-166.

Kolp, B.J. 1986. Winter wheat variety trial notes. Unpublished.

Pfeifer, R.P. and B.J. Kolp. 1958. Small grains for Wyoming. University of Wyoming Agricultural Experiment Station B 355.

Pochop, L. O. and R. D. Burman, 1987. Development of Evapotranspiration Crop Coefficients, Climatological Data, and Evapotranspiration Models for the Upper Green River. Project Completion Report, Project 59-6986-13, prepared to the Wyoming Water Development Commission and the Wyoming Water Research Center, 99 pp.

Pochop, L. O., R. L. Cornia, and C. F. Becker, 1973. Analysis of the effects of precipitation augmentation in the Great Plains Area of Wyoming. Final Report prepared for the Bureau of Reclamation, Contract 14-06-D-7156.

U. S. Dept. of Commerce, 1968. Climatic Atlas of the United States. June.

Wyoming Water Research Center, 1983. Water Resources Data System User's Guide, revised by Barbara Drury and Anne Travis, March.

ACKNOWLEDGEMENTS

The authors wish to extend their appreciation to Dr. Bernard J. Kolp, retired, Plant Science Division, for his assistance in gathering yield data, site descriptions and agrononomic information used in this study.

TABLE A1. SOIL WATER HOLDING PARAMETERS AT ARCHER

LOCATION	DEPTH (m)	FIELD CAPACITY MOISTURE CONTENT (%)	PERMANENT WILTING POINT MOISTURE CONTENT (%)	BULK DENSITY (g/cm^3)	AVAILABLE WATER HOLDING CAPACITY (mm/m)
N EAST	0.15	19.8	10.7	1.52	138
N EAST	0.46	26.8	13.9	1.49	192
N EAST	0.76	15.8	6.6	1.60	147
N MIDDLE	0.15	15.2	7.0	1.81	148
N MIDDLE	0.46	22.8	11.2	1.58	183
N MIDDLE	0.76	16.0	6.8	1.66	153
N WEST	0.15	15.0	5.9	1.68	153
N WEST	0.46	22.7	16.1	1.66	110
N WEST	0.76	23.2	13.5	1.59	154
S EAST	0.15	27.2	11.7	1.18	183
S EAST	0.46	23.6	11.9	1.58	185
S EAST	0.76	11.4	4.0	1.66	113
S MIDDLE	0.15	17.9	7.9	1.63	163
S MIDDLE	0.46	24.4	15.3	1.58	144
S MIDDLE	0.76	26.3	11.6	1.41	207
S WEST	0.15	23.4	11.3	1.46	177
S WEST	0.46	23.1	12.4	1.59	170
S WEST	0.76	12.7	5.3	1.68	124

TABLE A2. SOIL WATER HOLDING PARAMETERS AT GILLETTE

LOCATION	DEPTH (m)	FIELD CAPACITY MOISTURE CONTENT (%)	PERMANENT WILTING POINT MOISTURE CONTENT (%)	BULK DENSITY (g/cm^3)	AVAILABLE WATER HOLDING CAPACITY (mm/m)
NORTH	0.15	11.1	4.4	1.75	117
NORTH	0.46	24.7	15.3	1.53	144
NORTH	0.76	15.6	10.1	1.69	93
MIDDLE	0.15	10.0	3.5	1.76	114
MIDDLE	0.46	20.3	12.0	1.65	137
MIDDLE	0.76	20.6	10.2	1.44	150
SOUTH	0.15	10.7	3.6	1.71	121
SOUTH	0.46	18.2	11.6	1.72	114
SOUTH	0.76	14.8	9.4	1.71	92

TABLE A3. SOIL WATER HOLDING PARAMETERS AT SHERIDAN

LOCATION	DEPTH (m)	FIELD CAPACITY MOISTURE CONTENT (%)	PERMANENT WILTING POINT MOISTURE CONTENT (%)	BULK DENSITY (g/cm^3)	AVIALABLE WATER HOLDING CAPACITY (mm/m)
NORTH	0.15	26.3	12.3	1.48	207
NORTH	0.46	29.2	17.3	1.42	169
NORTH	0.76	25.7	15.9	1.51	148
MIDDLE	0.15	26.1	11.6	1.49	216
MIDDLE	0.46	26.4	13.2	1.53	202
MIDDLE	0.76	23.0	10.2	1.60	205
SOUTH	0.15	28.4	19.1	1.48	138
SOUTH	0.46	24.0	17.1	1.61	111
SOUTH	0.76	21.9	15.4	1.66	108
EAST	0.15	16.3	8.9	1.80	133
EAST	0.46	19.3	10.3	1.64	148
EAST	0.76	18.5	9.6	1.66	148
WEST	0.15	17.9	10.9	1.68	118
WEST	0.46	21.4	13.2	1.64	134
WEST	0.76	19.5	10.2	1.62	151

TABLE A4. ACTUAL VS MAXIMUM EVAPOTRANSPIRATION AT ARCHER **

YEAR		SEASON	VEGETATIVE	FLOWERING	YIELD FORMATION	RIPENING
	ETA	220.5	103.2	49.1	52.6	15.6
1951	ETM	391.0	106.3	87.0	133.9	63.8
	ETA/ETM	.564	.971	.565	.393	.244
	ETA	209.0	98.0	45.3	43.9	21.9
1952	ETM	437.1	124.7	83.7	161.4	67.3
	ETA/ETM	.478	.785	.542	.272	.325
	ETA	250.5	98.2	34.1	97.7	20.5
1956	ETM	443.7	120.2	94.9	161.6	67.0
	ETA/ETM	.564	.817	.360	.604	.305
	ETA	261.6	103.0	68.0	70.5	20.0
1957	ETM	397.2	106.1	71.9	147.2	72.0
	ETA/ETM	.658	.971	.946	.479	.278
	ETA	192.2	102.4	39.2	33.4	17.2
1958	ETM	441.2	115.2	98.5	163.3	64.3
	ETA/ETM	.436	.889	.399	.204	.267
	ETA	188.1	110.4	48.7	23.9	5.1
1959	ETM	424.9	116.7	79.3	161.1	67.8
	ETA/ETM	.443	.946	.615	.148	.075
	ETA	174.5	96.5	39.0	29.4	9.7
1960	ETM	461.2	143.0	90.7	160.6	66.9
	ETA/ETM	.378	.674	.430	.183	.144
	ETA	231.8	90.6	24.7	80.5	36.0
1962	ETM	447.4	140.6	95.6	144.2	67.0
	ETA/ETM	.518	.644	.258	.558	.538
	ETA	173.9	93.0	17.8	45.9	17.2
1963	ETM	465.2	136.6	95.5	158.9	74.1
	ETA/ETM	.374	.681	.186	.289	.232
	ETA	163.9	103.7	34.4	20.6	5.2
1964	ETM	414.3	106.2	98.7	137.6	71.8
	ETA/ETM	.396	.976	.348	.150	.073
	ETA	154.4	95.6	18.5	33.8	6.5
1966	ETM	449.5	126.1	89.5	158.3	75.7
	ETA/ETM	.343	.758	.207	.214	.086

TABLE A4. ACTUAL VS MAXIMUM EVAPOTRANSPIRATION AT ARCHER (Cont.)

YEAR		SEASON	VEGETATIVE	FLOWERING	YIELD FORMATION	RIPENING
	ETA	270.9	113.4	46.9	96.6	13.9
1968	ETM	404.0	117.3	68.8	153.8	64.1
	ETA/ETM	.670	.967	.682	.628	.217
	ETA	190.2	107.7	31.9	40.4	10.2
1969	ETM	447.8	144.0	90.8	141.5	71.5
	ETA/ETM	.425	.748	.351	.286	.142
	ETA	216.8	116.6	57.5	38.5	4.2
1971	ETM	417.4	121.8	76.7	154.6	64.3
	ETA/ETM	.519	.957	.749	.249	.065
	ETA	153.7	96.9	32.5	19.9	4.4
1973	ETM	410.1	97.7	88.9	150.1	73.4
	ETA/ETM	.375	.992	.365	.133	.060
	ETM	172.0	108.8	19.3	37.6	6.3
1974	ETM	460.6	130.8	94.7	161.5	73.5
	ETA/ETM	.373	.832	.203	.233	.086
	ETA	199.0	101.9	23.5	60.4	13.2
1975	ETM	403.6	108.4	85.0	141.2	69.0
	ETA/ETM	.493	.940	.277	.428	.191
	ETA	168.0	100.8	28.2	25.2	13.7
1976	ETM	450.4	135.1	88.8	153.4	73.1
	ETA/ETM	.373	.746	.318	.164	.187
	ETA	188.2	99.5	52.2	32.0	4.5
1978	ETM	447.5	137.9	89.9	148.9	70.9
	ETA/ETM	.421	.722	.581	.215	.064
	ETA	202.4	104.6	34.3	53.3	10.2
1979	ETM	436.0	130.4	83.4	150.0	72.2
	ETA/ETM	.464	.803	.411	.355	.141
	ETA	194.3	108.0	59.5	21.1	5.7
1980	ETM	437.4	118.7	82.5	160.6	75.7
	ETA/ETM	.444	.910	.722	.131	.075
	ETA	280.6	107.9	68.4	81.7	22.6
1981	ETM	459.6	154.2	77.4	155.5	72.5
	ETA/ETM	.611	.699	.884	.526	.312

TABLE A4. ACTUAL VS MAXIMUM EVAPOTRANSPIRATION AT ARCHER (Cont.)

YEAR		SEASON	VEGETATIVE	FLOWERING	YIELD FORMATION	RIPENING
	ETA	245.0	92.0	52.0	71.1	29.9
1982	ETM	385.6	115.7	78.3	130.3	61.3
	ETA/ETM	.635	.795	.664	.546	.488
	ETA	296.1	88.5	70.9	108.7	28.0
1983	ETM	365.0	88.5	70.9	138.0	67.6
	ETA/ETM	.811	1.000	1.000	.788	.414

*Evapotranspiration values are in millimeters.

TABLE A5. ACTUAL VS MAXIMUM EVAPOTRANSPIRATION AT GILLETTE*

YEAR		SEASON	VEGETATIVE	FLOWERING	YIELD FORMATION	RIPENING
	ETA	175.0	72.6	24.7	54.1	23.5
1951	ETM	396.3	102.1	95.9	131.1	67.3
	ETA/ETM	.442	.712	.258	.413	.349
	ETA	207.6	72.0	48.2	64.7	22.6
1952	ETM	457.9	138.8	90.9	158.6	69.6
	ETA/ETM	.453	.519	.531	.408	.325
	ETA	278.0	94.2	59.2	104.2	20.3
1953	ETM	406.3	102.2	76.0	153.6	74.5
	ETA/ETM	.684	.922	.779	.679	.273
	ETA	246.1	87.8	52.5	89.4	16.4
1955	ETM	430.5	126.6	90.1	139.8	74.0
	ETA/ETM	.572	.693	.582	.640	.222
	ETA	248.1	100.1	44.2	89.8	13.9
1957	ETM	416.1	109.7	79.6	149.5	77.3
	ETA/ETM	.596	.912	.555	.600	.180
	ETA	202.3	87.4	25.4	62.9	26.6
1958	ETM	332.0	93.1	80.1	112.4	46.3
	ETA/ETM	.609	.939	.317	.560	.574
	ETA	207.3	83.7	32.5	51.3	39.8
1959	ETM	425.0	114.3	79.2	161.9	69.7
	ETA/ETM	.488	.732	.411	.317	.571
	ETA	199.9	81.0	31.2	67.3	20.4
1960	ETM	447.4	125.3	93.0	155.8	73.3
	ETA/ETM	.447	.646	.336	.432	.279
	ETA	168.5	91.4	39.1	29.0	9.0
1961	ETM	442.8	102.2	89.1	175.3	76.3
	ETA/ETM	.381	.895	.439	.165	.117
	ETA	283.8	75.3	49.3	107.4	51.9
1962	ETM	342.7	113.8	69.7	107.4	51.9
	ETA/ETM	.828	.661	.707	1.000	1.000
	ETA	312.1	115.3	50.7	128.0	18.1
1963	ETM	452.8	128.4	90.3	158.0	76.0
	ETA/ETM	.689	.898	.561	.810	.238

TABLE A5. ACTUAL VS MAXIMUM EVAPOTRANSPIRATION AT GILLETTE (Cont.)

YEAR		SEASON	VEGETATIVE	FLOWERING	YIELD FORMATION	RIPENING
	ETA	318.1	88.7	71.3	101.8	56.3
1964	ETM	419.2	108.8	96.1	139.4	74.9
	ETA/ETM	.759	.815	.742	.730	.752
	ETA	205.4	101.9	27.7	43.9	31.9
1966	ETM	441.6	113.7	86.3	162.3	79.2
	ETA/ETM	.465	.896	.321	.271	.403
	ETA	311.9	87.6	58.9	119.7	45.7
1967	ETM	405.0	107.8	86.0	141.5	69.8
	ETA/ETM	.770	.813	.685	.846	.655
	ETA	248.1	84.3	40.7	100.6	22.6
1968	ETM	384.8	103.5	68.9	144.4	68.0
	ETA/ETM	.645	.815	.590	.696	.332
	ETA	259.7	83.2	76.7	86.8	13.0
1970	ETM	411.5	90.3	89.7	156.9	74.5
	ETA/ETM	.631	.921	.854	.553	.175
	ETA	236.1	99.9	39.8	71.7	24.8
1971	ETM	435.7	121.9	84.4	157.3	72.1
	ETA/ETM	.542	.820	.471	.456	.344
	ETA	244.4	99.3	41.1	76.0	28.0
1972	ETM	435.3	116.8	92.6	158.2	67.7
	ETA/ETM	.561	.850	.444	.480	.414
	ETA	217.9	101.0	39.7	66.1	11.2
1973	ETM	419.4	101.4	87.7	151.4	78.9
	ETA/ETM	.520	.996	.452	.436	.142
	ETA	287.0	87.8	66.3	104.9	28.0
1975	ETM	386.7	89.5	83.6	138.8	74.8
	ETA/ETM	.742	.981	.794	.756	.374
	ETA	209.9	87.5	44.8	57.9	19.7
1977	ETM	475.9	133.9	100.1	168.1	73.8
	ETA/ETM	.441	.654	.447	.344	.267
	ETA	310.2	97.2	89.4	103.8	19.8
1978	ETM	435.8	126.8	89.4	146.3	73.4
	ETA/ETM	.712	.767	1.000	.710	.269

* Evapotranspiration values are in millimeters.

TABLE A6. ACTUAL VS MAXIMUM EVAPOTRANSPIRATION AT SHERIDAN*

YEAR		SEASON	VEGETATIVE	FLOWERING	YIELD FORMATION	RIPENING
	ETA	230.5	92.4	45.8	74.8	17.4
1950	ETM	391.2	94.7	83.4	140.5	72.7
	ETA/ETM	.589	.976	.550	.533	.240
	ETA	236.9	88.1	29.8	88.7	30.3
1951	ETM	409.8	109.0	100.8	132.7	67.4
	ETA/ETM	.578	.808	.296	.669	.449
	ETA	358.8	93.2	59.6	69.7	36.2
1952	ETM	462.5	136.9	93.3	161.9	70.4
	ETA/ETM	.560	.681	.639	.431	.515
	ETA	256.9	97.3	44.9	95.2	19.5
1953	ETM	416.5	104.8	77.2	156.7	77.8
	ETA/ETM	.617	.928	.582	.608	.251
	ETA	196.0	91.7	36.2	56.0	12.2
1954	ETM	431.5	99.6	103.5	142.4	86.0
	ETA/ETM	.454	.920	.350	.393	.142
	ETA	295.1	99.3	55.8	100.6	39.4
1955	ETM	425.2	115.2	93.7	146.2	70.1
	ETA/ETM	.694	.862	.596	.688	.562
	ETA	299.9	108.9	49.7	113.4	27.9
1957	ETM	433.9	117.0	85.7	153.1	78.1
	ETA/ETM	.691	.930	.579	.741	.357
	ETA	202.1	93.0	26.9	68.3	13.9
1960	ETM	465.4	132.3	96.3	160.6	76.2
	ETA/ETM	.434	.703	.279	.425	.183
	ETA	231.7	94.8	64.6	58.9	13.5
1961	ETM	458.6	114.1	90.6	176.9	76.9
	ETA/ETM	.505	.830	.713	.333	.175
	ETA	267.6	101.7	41.8	95.0	29.1
1962	ETM	457.2	135.8	95.2	154.8	71.4
	ETA/ETM	.585	.749	.439	.614	.408
	ETA	332.6	112.3	61.1	102.3	56.9
1964	ETM	437.4	114.2	101.4	145.4	76.4
	ETA/ETM	.761	.984	.603	.704	.744

TABLE A6. ACTUAL VS MAXIMUM EVAPOTRANSPIRATION AT SHERIDAN (Cont.)

YEAR		SEASON	VEGETATIVE	FLOWERING	YIELD FORMATION	RIPENING
	ETA	214.8	91.4	46.1	59.8	17.4
1965	ETM	425.0	117.6	82.9	152.8	71.7
	ETA/ETM	.505	.778	.555	.392	.243
	ETA	214.5	107.0	45.7	46.0	15.8
1966	ETM	449.1	114.5	89.6	164.8	80.3
	ETA/ETM	.478	.934	.510	.279	.197
	ETA	282.9	97.5	43.9	108.8	32.8
1967	ETM	403.5	101.6	88.6	142.6	70.7
	ETA/ETM	.701	.959	.495	.763	.464
	ETA	281.6	89.8	47.8	112.0	32.1
1968	ETM	391.0	103.3	74.3	146.4	66.9
	ETA/ETM	.720	.869	.643	.765	.479
	ETA	300.7	95.8	87.6	101.4	16.0
1970	ETM	431.0	97.3	95.0	163.8	74.9
	ETA/ETM	.698	.985	.921	.619	.213
	ETA	269.8	116.9	54.8	85.0	13.1
1971	ETM	431.0	117.8	85.3	158.3	69.6
	ETA/ETM	.626	.993	.642	.537	.189
	ETA	252.3	95.3	43.6	85.8	27.7
1972	ETM	427.8	114.0	89.3	158.7	65.8
	ETA/ETM	.590	.836	.488	.540	.421
	ETA	265.2	94.2	66.2	67.7	37.0
1973	ETM	405.0	94.2	87.7	148.8	74.2
	ETA/ETM	.655	1.000	.755	.455	.499
	ETA	208.1	107.7	36.8	53.5	10.1
1974	ETM	421.2	119.1	74.2	153.5	74.4
	ETA/ETM	.494	.904	.496	.348	.136
	ETA	313.6	82.2	80.8	119.6	31.1
1975	ETM	382.8	82.2	81.8	142.4	76.5
	ETA/ETM	.819	1.000	.988	.840	.407
	ETA	250.3	114.1	39.9	71.7	24.6
1976	ETM	459.5	132.0	97.0	152.1	78.3
	ETA/ETM	.545	.864	.411	.472	.314

TABLE A6. ACTUAL VS MAXIMUM EVAPOTRANSPIRATION AT SHERIDAN (Cont.)

YEAR		SEASON	VEGETATIVE	FLOWERING	YIELD FORMATION	RIPENING
	ETA	284.1	96.0	57.7	105.8	24.6
1977	ETM	456.5	129.7	99.0	156.6	71.2
	ETA/ETM	.622	.740	.583	.675	.346
	ETA	338.6	110.9	91.1	109.9	26.7
1978	ETM	452.2	141.4	91.3	147.2	72.4
	ETA/ETM	.749	.785	.998	.747	.369
	ETA	232.6	100.1	37.1	70.2	25.1
1979	ETM	419.5	109.6	86.9	149.3	73.7
	ETA/ETM	.554	.914	.427	.470	.341
	ETA	246.1	91.1	45.5	91.2	18.3
1980	ETM	467.5	133.0	99.7	156.5	78.3
	ETA/ETM	.526	.685	.457	.582	.234
	ETA	264.2	96.5	61.8	89.1	17.4
1981	ETM	455.1	139.2	82.1	156.0	77.8
	ETA/ETM	.581	.693	.746	.571	.224
	ETA	250.4	91.3	43.4	89.3	26.4
1982	ETM	392.0	105.5	81.2	135.6	69.7
	ETA/ETM	.639	.865	.535	.659	.378
	ETA	212.0	93.3	53.0	54.7	11.0
1983	ETM	406.3	102.9	74.3	152.8	76.3
	ETA/ETM	.522	.906	.713	.358	1.44

* Evapotraspiration values are in millimeters.